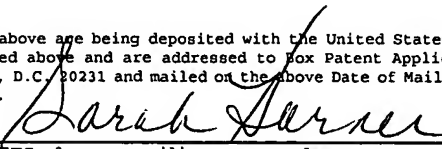# SPECIFICATION

Docket No. 20480.139

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN that we, Eric Berger and Diethelm Walter, citizens of the United States of America and the Federal Republic of Germany, respectively, and residing in the State of Texas, U.S.A. and the Federal Republic of Germany, respectively, have invented new and useful improvements in a

METHOD OF SELECTING A SOIL STABILIZATION PROTOCOL FOR A CONSTRUCTION SITE

of which the following is a specification:

BACKGROUND OF THE INVENTION

1   **1.   Field of the Invention:**

2

3   The present invention generally relates to measuring soil characteristics and, more particularly,

4   to using measurements of soil conductivity to (a) estimate in real time the suitability of calcium-based

5   soil stabilization methods and (b) estimate the need for laboratory analysis of soil samples.

6

7   **2.   Description of the Prior Art:**

8

9   Stabilization of clay soils at construction sites using low-cost, calcium-based soil stabilization

10   methods such as the application of lime, Portland cement or flyash, is a routine practice to prevent

11   pavement or structural distresses in structures built upon such clay soils. These distresses, which are

12   expensive to remediate, arise because of the presence of expansive minerals such as ettringite and

13   thaumasite in the soil. These minerals are formed in clay soils having significant soluble sulfate (SO_4)

14   content when calcium, aluminum, and water are also present. Aluminum, in the form of aluminum

15   silicate (Al_2SiO_3), is a prevalent constituent of clay soils, and calcium is present in the materials used

16   to stabilize such soils, often in the presence of water. Thus, in the right combinations, these three

17   components (aluminum, calcium and water), plus sulfate compounds present in the soil, may induce

18   the formation of expansive minerals, which can absorb and hold very large amounts of water, swelling

19   up to 250% by volume. Under these conditions, the sulfate-induced distress can cause extensive

20   damage to structures supported on such unstable soils. Therefore, when using lime (CaO), e.g., to

21   stabilize clay soils that have significant soluble sulfates, it is recommended to apply the lime as a lime

22   slurry. The lime slurry (to provide sufficient water for the expansive minerals to form) is applied to

23   the clay soil, followed by sufficient 'mellowing' time (typically one to seven days) to pass before

24   compacting of the soil is performed. In this way, the expansion is allowed to reach an equilibrium

25   condition before paving or other structures are constructed on the soil.

26

1   Sulfate-induced distress (sometimes called sulfate heave, due to the formation of ettringite)

2   can arise both because of the presence of sulfates in soils treated using calcium-based materials and

3   because of an uneven distribution of expansive minerals in the soil of the construction site being

4   treated. Soil sampling and laboratory analysis of the samples can be used to map a site to determine

5   its composition in order to decide whether to apply soil stabilization to remediate the site. However,

6   such testing is laborious and expensive, involving disturbing the site to take core samples, one sample

7   at a time, handling and analyzing the samples, etc. These disadvantages are magnified by the fact that

8   sulfates tend to occur unevenly in seams in the soil. Thus, routine testing using a practical density

9   of measurements often misses the location and extent of such a seam because of an insufficient

10   number of samples. Such testing may result in treating a much larger area than necessary or in

11   overlooking an area that needs to be treated because it was not discovered, or worse, causing sulfate

12   heave in areas of the site treated with lime slurry that also have an undetected high concentration of

13   soluble sulfates. Yet, increasing the number of samples raises the costs of the survey to locate

14   sulfate-bearing soils that must be treated with soil stabilization techniques.

15

16   What is needed is a non-intrusive, real-time method of testing or screening a construction site

17   for the presence of sulfate-bearing soil that will enable a reliable determination of the need for

18   conventional soil stabilization only in those portions of the construction site that need the treatment.

19   Further, the method should enable identification of areas within the construction site in which soil

20   samples must be taken to determine the sulfate concentration thereof and assist in the selection of the

21   best stabilization method for the particular area.

SUMMARY OF THE INVENTION

Experimentation with several devices for measuring soil conductivity and the techniques of their use, and devising a way to interpret the results of test data obtained, has resulted in the development of a method for selecting, in real time, a soil stabilizing protocol for construction sites. The inventive method, based on screening construction sites for the presence of soluble sulfate compounds in clay-bearing soils, does not involve time-consuming and expensive chemical analysis of soil samples taken from the site. Moreover, the method can be performed on a typical site by one person in a few hours' time or less, and the method is readily adaptable to a programmable process that controls the measurement activity and records the data for analysis. Further, the method is amenable to using location data provided by a global positioning satellite (GPS) system to enable mapping of the soil measurement data. The screening method identifies the location and concentration of sulfates in a surveyed area and provides an indication of when calcium-based soil stabilization treatment, such as the application of a lime slurry, is appropriate for the site and when it is not recommended. In the latter case, the sulfate-rich seams are localized with sufficient specificity by the method of the present invention to considerably reduce the expense of chemically analyzing soil samples from the sulfate-rich seams to enable selection of the best stabilizing method.

Accordingly there is disclosed a method of selecting in real time a soil stabilizing protocol for clay-bearing soils occurring in construction sites, comprising the steps of: obtaining soil conductivity data values at selected locations within a defined site without disturbing the surface of the soil; correlating the soil conductivity data values with corresponding estimates of soluble sulfate levels; recommending a calcium-based soil stabilizing protocol if the estimated level of soluble sulfates is less than a predetermined threshold; and performing a laboratory analysis of soil samples from selected portions of the defined site wherein the estimated soluble sulfate concentration equals or exceeds the predetermined threshold.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a pictorial view of a cross section of a construction site having a seam of high sulfate concentration in a clay-bearing soil and an operator performing a soil conductivity survey according to the method of the present invention;

Figure 2 illustrates a flow diagram of the method of performing a soil conductivity survey according to the present invention; and

Figure 3 illustrates one embodiment of an electromagnetic soil conductivity meter for use in practicing the method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Figure 1, there is illustrated a pictorial view of a cross section of a construction site 10 having a seam of high sulfate concentration near the surface of the site in a clay-bearing soil and an operator performing a soil conductivity survey according to the method of the present invention. The drawing is not to scale, the depth dimension being exaggerated for clarity. The construction site 10 has a surface 12 that is bounded by borders 14, 16, 18 and 20, which intersect at the corners A, B, C and D, forming a rectangular shaped site 10. A portion of the depth of the construction site 10 is indicated by the corners A', B', C' and D', which respectively locate the corresponding points beneath the surface 12 of the site 10 directly below the corners A, B, C and D. A seam 22 of sulfate-rich soil runs through the site 10 along and just below the surface 12, passing across the border 20 and the border 14 as it curves across and through the site 10. A cross-section 30 of the seam 22 is shown in the vertical plane that extends below the border 14. Similarly, a cross-section 32 of the seam 22 is shown in the vertical plane that extends below the border 20.

Continuing with Figure 1, an electromagnetic ground conductivity meter 40 is shown being carried by an operator 42, walking along a path 44 that may be a portion of a surveying grid 46 superimposed upon the surface 12 of the construction site 10. The ground conductivity meter is preferably a Model EM38, manufactured by Geonics Limited, located in Mississauga, Ontario, Canada L5T 1C6. The Geonics Limited firm can also be accessed at www.geonics.com. For a description of experimental work using this instrument, see the article entitled "Equipment and methods For Field Screening Indicating Soluble Sulfates," by Dr. Thomas M. Petry, P.E. and Eric Berger, P.E., published in the Proceedings of the Texas Section of the American Society of Civil Engineers for the Fall Meeting, October 2 - 5, 2002, which article is incorporated herein by reference.

The Model EM38 soil conductivity meter is a portable unit contained in an elongated tube, one meter in length, which is carried along and may be placed parallel to the surface 12 of the site 10 and oriented along a grid line or path 44. In use, the measurements are made with the EM38 without disturbing the surface of the earth. No holes or core samples need be dug to take readings with the

1   EM38. The testing is completely non-invasive and non-destructive. This is an important advantage

2   because it enables a low-cost survey to be made and requires no other tools or personnel to perform

3   the survey. Briefly, the device operates as follows. A transmitter antenna at one end of the meter

4   radiates a signal generated within the EM38 into the earth. The magnetic field produced by the signal

5   induces galvanic currents to flow in any nearby soil that is conductive - i.e., has a relatively low

6   resistivity - by virtue of the presence of salts, such as sodium chloride (NaCl) and sulfates (e.g., SO_4),

7   in the soil. Magnetic fields set up in the soil by the galvanic currents themselves are then sensed or

8   picked up by a receiving antenna in the opposite end of the meter and displayed on a readout in

9   milliSiemens per meter (mS/m), a unit of soil conductivity.

10

11   Experimentation has shown that there is a fairly well defined relationship between the

12   conductivity of the soil and the concentration of soluble sulfates in the soil. For example, a soil

13   conductivity measurement of 280 mS/m correlates with a fairly high probability (62%) to a sulfate

14   concentration of approximately 3000 parts-per-million (ppm) or above. The present invention

15   exploits this relationship in a protocol that has been developed to predict the need for and suitability

16   of calcium-based soil stabilization methods for a construction site. For example, sulfate

17   concentrations less than 3000 ppm are readily treatable using calcium-based soil stabilization

18   methods. The soils in those areas indicated by the screening steps as having a sulfate concentration

19   above 3000 ppm (i.e., wherein the soil conductivity is above 280 mS/m) should be sampled and the

20   samples analyzed chemically to determine their actual sulfate concentration. This is because the soil

21   conductivity meter does not directly provide an accurate measure of the actual soluble sulfate

22   concentration. Rather, the soil conductivity meter measures soil conductivity, which is affected by

23   the presence of several constituents in the soil including soluble sulfates. However, this ability to

24   accurately measure soil conductivity makes the EM38 particularly useful as a screening instrument

25   on construction sites.

26

27   Referring to Figure 2, there is illustrated a flow diagram of the method of performing a soil

28   conductivity survey, which includes a protocol for the interpretation and application of the instrument

29   readings as adapted to construction sites, according to the present invention. The Flow begins with

1   a Start block 100, followed by an operation in step 102 to scan the defined construction site to obtain

2   measurements of the soil conductivity at a plurality of selected intervals over the surface of the site.

3   For example, a grid may be superimposed over the surface 12 of the site 10, to identify the points on

4   the surface where data value readings will be taken. The mesh of the grid - i.e., the spacing of the

5   data points - may be selected depending on such factors as the dimensions of the site, the expected

6   characteristics to be identified by the magnetometer, the level of detail or resolution of the data

7   required, and so on. Next, in step 104, the soil conductivity data values are logged - i.e., recorded

8   or stored in some form, and in association with information identifying the location or position of the

9   reading on the site 10 - for later use. Information on the location of the readings may be in the form

10   of coordinates from a global positioning system (GPS) device or from coordinates defined relative

11   to a datum or baseline, for example. The information may be entered manually, or automatically

12   when a computer-controlled system is used in conjunction with the EM38. In this way a map of the

13   soil conductivity data values is developed. From such a map it is a simple matter to note the high-

14   sulfate areas on the map in which soil samples may be required.

15

16   Continuing with Figure 2, in step 106, the data values for the soil conductivity are converted

17   to levels of sulfate concentration to enable a direct indication of the need for calcium-based soil

18   stabilization. As indicated previously, this conversion is in the nature of a threshold defined for soil

19   conductivity values above 280 mS/m. That is, if the soil conductivity reading exceeds the 280 mS/m

20   figure, then it indicates, with a high probability, that the concentration of soluble sulfates in the soil

21   at that location exceeds 3000 ppm.

22

23   One material often present in soils that affects the soil conductivity is sodium chloride (NaCl).

24   As is well known, sodium chloride ions are good transporters of electric current, and its presence in

25   the soil contributes to the readings measured by the soil conductivity meter. The degree of influence

26   upon the readings may be accounted for in steps 108 and 110 of Figure 2. In step 108, the soil is

27   tested for the presence of NaCl ions. If they are present, the data values read by the soil conductivity

28   meter may be adjusted accordingly in step 110. It is somewhat like adjusting for the level of

29   background noise in an electrical measurement. The adjustment is made by dividing the estimated

1   level of sulfates by a factor given by the average number of soluble sulfates divided by the total

2   number of soluble ions (the sum of soluble sulfates + sodium chloride ions) in the soil of each of a

3   plurality of representative soil samples of the defined site 10 as determined by laboratory analysis of

4   the representative soil samples from the defined site 10.

5

6   Following step 110, or step 108 if no sodium chloride ions are present in the soil at the site

7   10, the flow proceeds to step 112 to compare the data value read by the soil conductivity meter 40

8   with the threshold level of 280 mS/m. If, in step 114, the data values are less than the threshold, the

9   flow advances to step 116 to accumulate the data value in association with location coordinates in

10   a storage medium for later use. This data may be stored in a table named Set A, for convenience.

11   A first set, "Set A," includes data values for soil having sulfate concentrations below 3000 ppm and

12   would thus be amenable to the conventional calcium-based soil stabilization method. After step 116,

13   the data values in Set A may be plotted on a map in step 118. The map developed in step 118 may

14   then be a convenient form in which to recommend, in step 120, those portions of the defined site 10

15   which may be treated with calcium-based stabilization, e.g., with lime slurry. After making the

16   recommendation available in step 120, the process ends at step 122.

17

18   Returning to step 114 in Figure 2, and if it was determined there that a given data value is not

19   below the threshold of 280 mS/m, the flow skips to step 130, where the data values may be

20   accumulated, in association with location coordinates in another storage medium location, identified

21   as a second set, "Set B." Set B is designated to accumulate data values that exceed the threshold of

22   280 mS/m. The data values of Set B may also be plotted or mapped in step 132 to provide an easily

23   perceived and evaluated presentation of the results of the soil conductivity screening. These data

24   values record a level of sulfates that is considered high and for which it cannot be recommended that

25   conventional calcium-based stabilization are appropriate without determining the actual sulfate

26   concentration. Thus, the data values in Set B must be subjected to chemical analysis of soil samples

27   from the mapped areas in a laboratory. The samples are collected in step 134 and analyzed in step

28   136.

29

1   Returning to Figure 2, the actual sulfate concentrations are evaluated in step 138 to determine

2   if the level is below or above the threshold of 3000 ppm. If the lab results show that a sample

3   contains less than 3000 ppm of sulfates, the location represented by that soil sample is part of the Set

4   A data; thus the data value is transferred to Set A. Any other data values shown to be below the

5   threshold may then be transferred to Set A to update the Set A map for the site. In effect, the site

6   area corresponding to Set A is redefined. If the lab results show that the sample contains more than

7   3000 ppm, the data value is used to update the value stored in Set B. These values are used to update

8   the Set B map in step 142, as before for the Set A data values in step 118. The Set B map may then

9   be reviewed and evaluated for alternate remediation as necessary. After updating Set B with the

10   actual measured sulfate values in step 142, the flow ends at step 122.

11

12   Referring to Figure 3, there is illustrated one embodiment of an electromagnetic soil

13   conductivity meter 150 for use in practicing the method of the present invention. The figure shows

14   some of the general features of the Model EM38 Ground Conductivity Meter manufactured by

15   Geonics Ltd. of Mississauga, Ontario, Canada. The meter includes a body 152, which is

16   approximately 42 inches in length. Within the first end 154 is a primary source coil which radiates

17   a 14,6 KHz signal into the soil. Within the second end 156, opposite the first end 154, is a sensor coil

18   which detects the presence of a magnetic field in the soil that is set up by eddy currents induced in

19   the conductive portions of the soil by the signal from the primary source coil at the first end 154. The

20   detected signal is converted to a soil conductivity reading displayed on the readout 158, in units of

21   milliSiemens per meter. The meter 150 may be carried by a handle160, which is attached to the first

22   and second ends 154, 156 of the meter body 152 by rods 162. In use, after calibration, the meter 150

23   is carried to the desired measurement position, placed on the ground and the reading taken from the

24   display 158.

25

26   It will be recalled that the soil conductivity meter does not actually measure the sulfate

27   concentration; however, it does enable a reliable inference to be made from soil conductivity data

28   whether the sulfate concentration is high or low. If the sulfate concentration is indicated to be high,

29   then the recommendation is that chemical analysis of soil samples should be performed to determine

1   the actual level. However, it will be appreciated that the method of the present invention provides

2   a useful way to estimate the sulfate levels rapidly and at relatively low cost, enabling many projects

3   to proceed without the delay that might accompany sending the soil samples to a lab for testing.

4   Since sulfates tend to occur in seams, often occupying on a small fraction of the total area of the

5   construction site 10, the location of seams of high sulfate levels may be such as to not impede the

6   construction plans for the site. Further, since the seams of sulfate compounds are usually a small

7   portion of the site area, the sampling and analysis of samples from the seamed area represents only

8   a relatively small expense of time and resources. Moreover, the data from the chemical analysis

9   enables the stabilization treatment to be tailored to the particular concentrations of sulfates at the site.

10

11   While the invention has been shown in only one of its forms, it is not thus limited but is

12   susceptible to various changes and modifications without departing from the spirit thereof.